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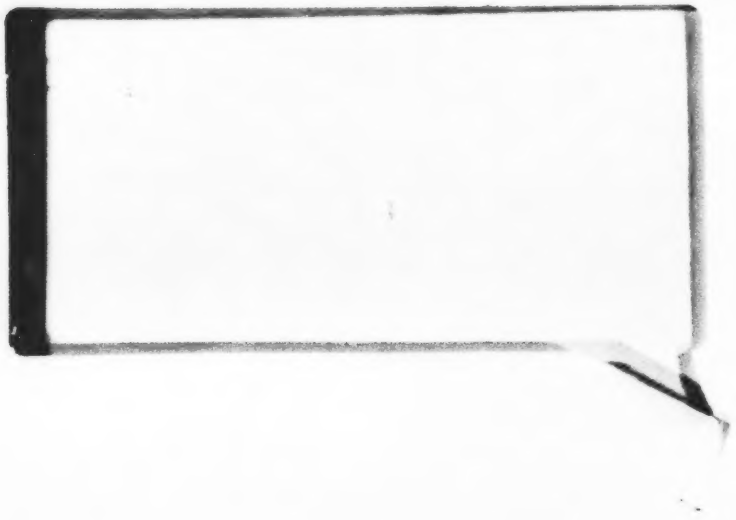

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TP 4851E

FABRICATION, TEST, CALIBRATION AND EVALUATION OF A ROAD ROUGHNESS MEASURING DEVICE

By

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September 1983

Prepared for the

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17. Abstract

This report presents the results of a calibration and evaluation of a new concept in road roughness measuring equipment design. Currently available roughness measuring equipment is installed in vehicles as an add on item. The equipment described in this report was designed to function exclusively as a road roughness measuring system as opposed to automobile based devices which may serve other purposes as well. The sensor is installed in a specially built trailer and a control and monitoring package has been designed to adapt to various tow vehicles.

PURD means portable universal roughness device. The trailer is designed to be suitable for shipment on standard air cargo pallets. The removable tongue and electronic control unit stow inside for shipment. The ballast is removable to significantly decrease weight.

PURD provides a response type measurement based on acceleration. Speed correction and statistical correlations with existing devices have been developed to enable its use in place of direct measuring equipment.

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	R.N. Sabounghi

17. Résumé

Ce rapport rend compte des travaux d'étalonnage et d'évaluation d'un analyseur de profil en long de conception inédite. Alors que la plupart des appareils d'auscultation des chaussées sont embarqués et polyvalents, celui-ci a été conçu à ce seul usage. Il se compose d'une remorque portant un palpeur ainsi qu'un appareillage de commande et de contrôle adaptable à divers véhicules de traction.

Il est désigné par le sigle PURD qui signifie dispositif universel et transportable, notamment par avion, sur palettes normalisées. La barre d'accouplement et l'unité de commande électronique sont escamotables, facilitant le transport. Le lest s'enlève pour réduire le poids de l'appareil.

Le PURD est un appareil de type accélérométrique capable de remplacer les appareils d'auscultation directe des chaussées, en raison des méthodes mises au point pour la correction des mesures en fonction des vitesses d'essai et aussi grâce aux corrélations statistiques établies avec les résultats fournis par d'autres types d'appareil.

18. Mots-clés	19 Diffusion
Profil en long. Analyseur. Accéléromètre.	Le CDT dispose d'un nombre limité d'exemplaires.

20. Classification de sécurité (de ce rapport)	21. Classification de sécurité (de cette page)	22. Nombre de pages	23. Prix
Aucune	Aucune	35	Nil

PROJECT TEAM

The project team for Highway Products International Inc. was composed of:

Mr. D. Kobi

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Mr. K. Smeaton

Mr. N. Bethune

Mr. C. Coley

Acknowledgements

The author gratefully acknowledges the advice and assistance of Pavement Management Systems Ltd., particularly Mr. Kirk Smeaton, and Federal Technical Surveys Inc., in particular Mr. Brandt Henderson. Pavement Management Systems has kindly authorized the use of excerpts from some of its reports.

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1. INTRODUCTION

The purpose of this project was to fabricate, test, calibrate and evaluate a Portable Universal Roughness Device (PURD). The device measures road roughness by accumulating the vertical components of the axle movements of a vehicle as it moves over the road. The total vertical movement is then related to a fixed horizontal distance travelled to provide a quantitative means of comparing different sections of road with one another. Since the device measures the roughness of the pavement in terms of the response of the axle and tires, this technique is known as response type measurement.

Currently there are several other techniques in widespread use for measuring pavement roughness. There is a large market for a new device such as PURD if its performance can be scientifically proven and its price is competitive. The competitive devices have good performance records and have been well accepted. Maintenance problems, vehicle dependence and obsolescent technology are their major drawbacks. PURD must be technically proven to be equal or superior to gain acceptance as an international standard.

It is of primary importance to develop a device with demonstrated repeatability. Hence the work undertaken in this project. The prototype device was designed around a compact, specially designed trailer. The trailer was put through two phases of testing. The objectives of the first phase were to calibrate the PURD in terms of existing devices and to establish repeatability. The second phase was intended to accomplish a significant data collection assignment for a Canadian province to evaluate performance and compare the PURD to other devices in use.

2. DEVICE DESCRIPTION

2.1 Mechanical

PURD is designed to be a trailer package in order to provide the measuring instrument with a predictable environment as far as the vehicle is concerned. Since the measurement of roughness is made in terms of the response of the tires and axle assembly, it is necessary to control, to some degree, the performance of these components.

A rear axle assembly from a 1981 Oldsmobile Omega front wheel drive car was selected because it offers a straight through axle design and coil spring suspension with sway arm. The straight through axle provides a convenient place to mount the accelerometer for measurement of effects from both wheels. The coil springs allow the installation of adjustable air bags so that the stiffness may be controlled to eliminate aging effects. The sway arm improves handling and control. A ballast box of welded plate steel construction is mounted on a sturdy but light frame constructed from rectangular steel tubing.

The ballast box allows the load to be adjusted for a) reduced shipping weight and b) as an aid to achieving repeatability over time. Pure silica sand is the recommended ballast because of its uniformity world-wide. Gas type shock absorbers are used and a test specification is provided for measuring their repeatability.

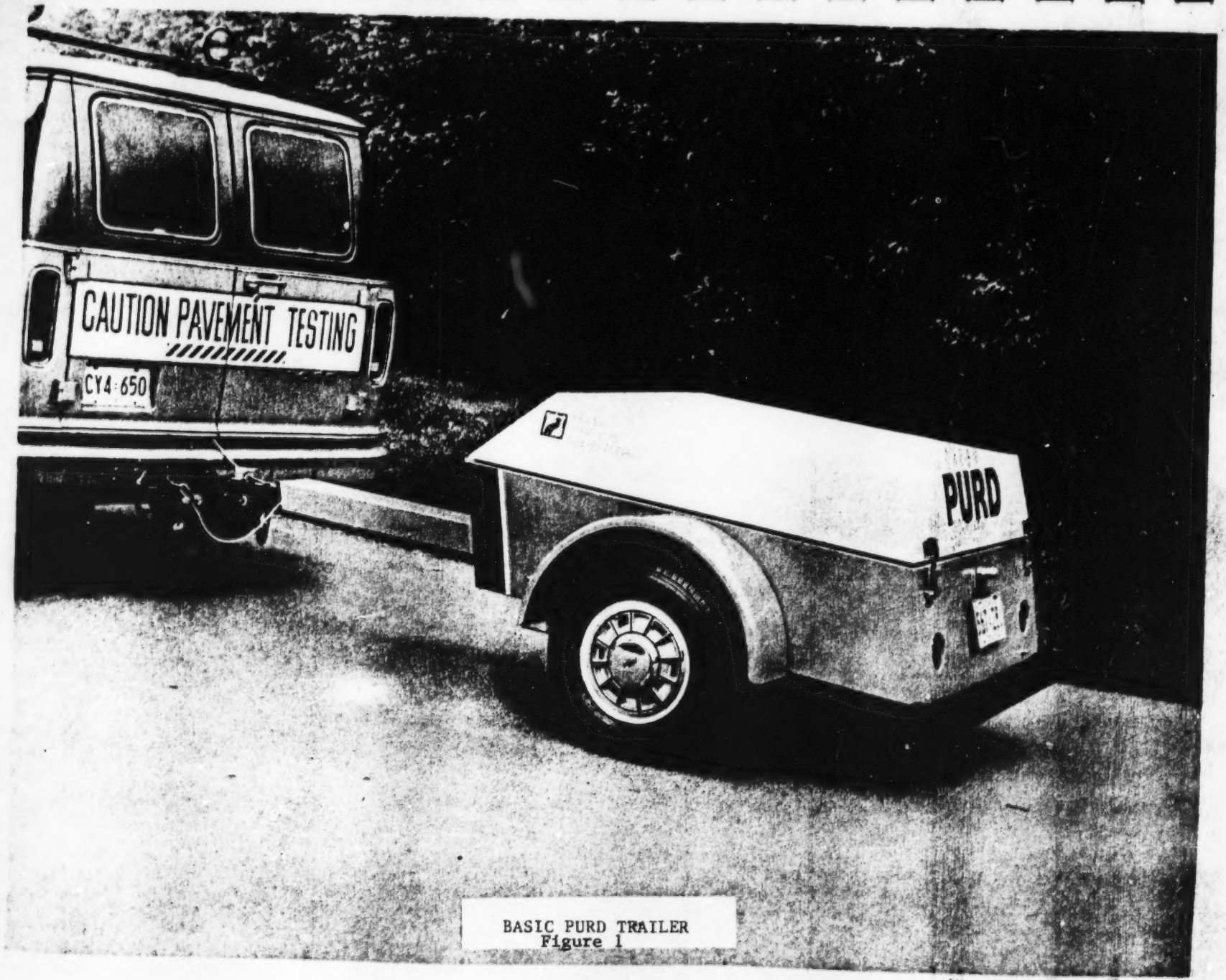
The sheet metal body offers only weather protection and general streamlining. The tongue is designed to be removable and can be stored inside the lid for shipping or storage.

The completed unit is shown in Figures 1, 2 and 3.

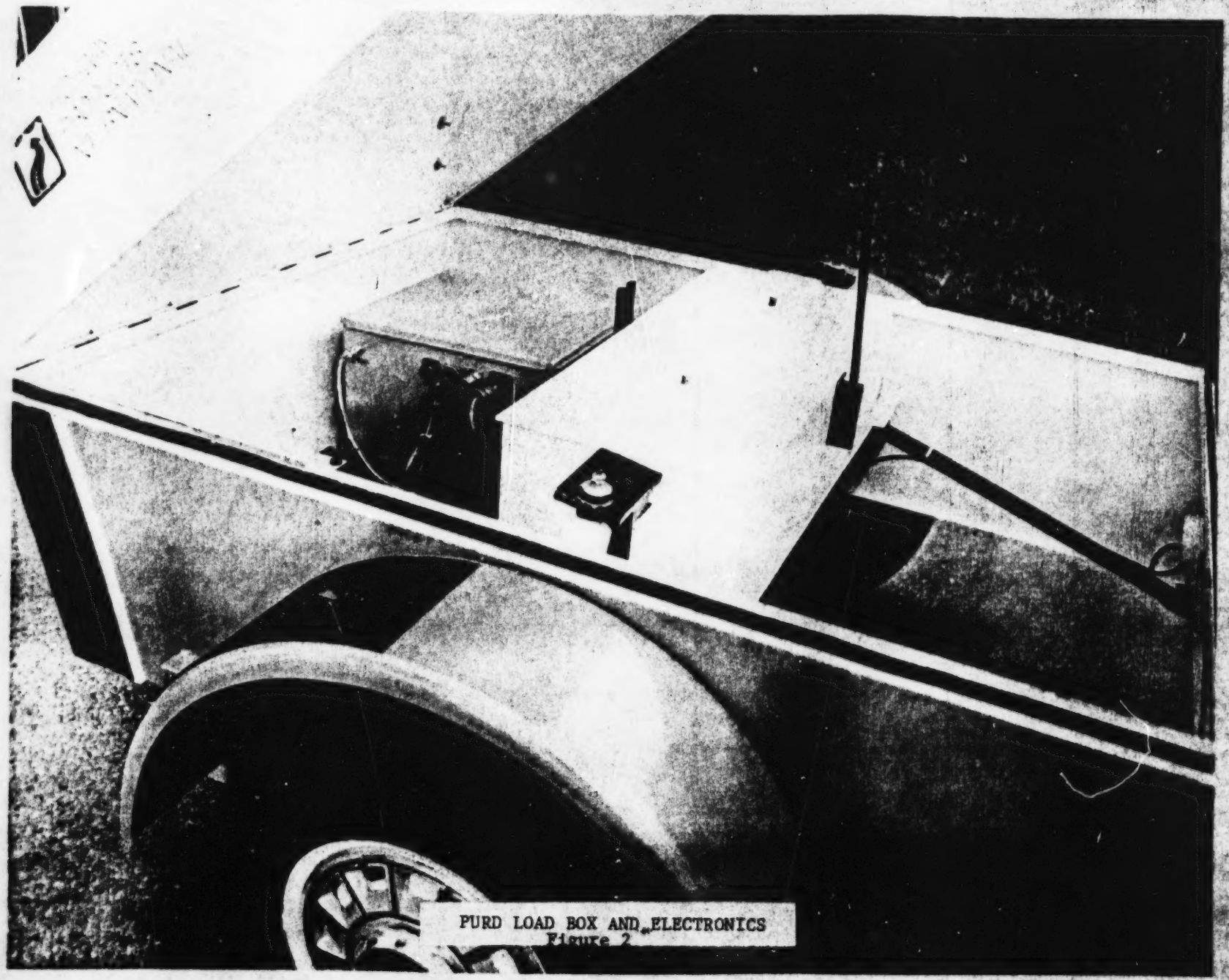
2.2 Electrical

The electronics package (designed to fit on the passenger seat in the tow vehicle) is micro-processor controlled using a Z80 processor. Operator control information is entered through switches on an integral control panel. Output information consistency of the RIDE number, ELAPSED TIME and DISTANCE TRAVELLED is presented on a built in light emitting diode display. An optional strip printer and/or 25 cm CRT have also been provided.

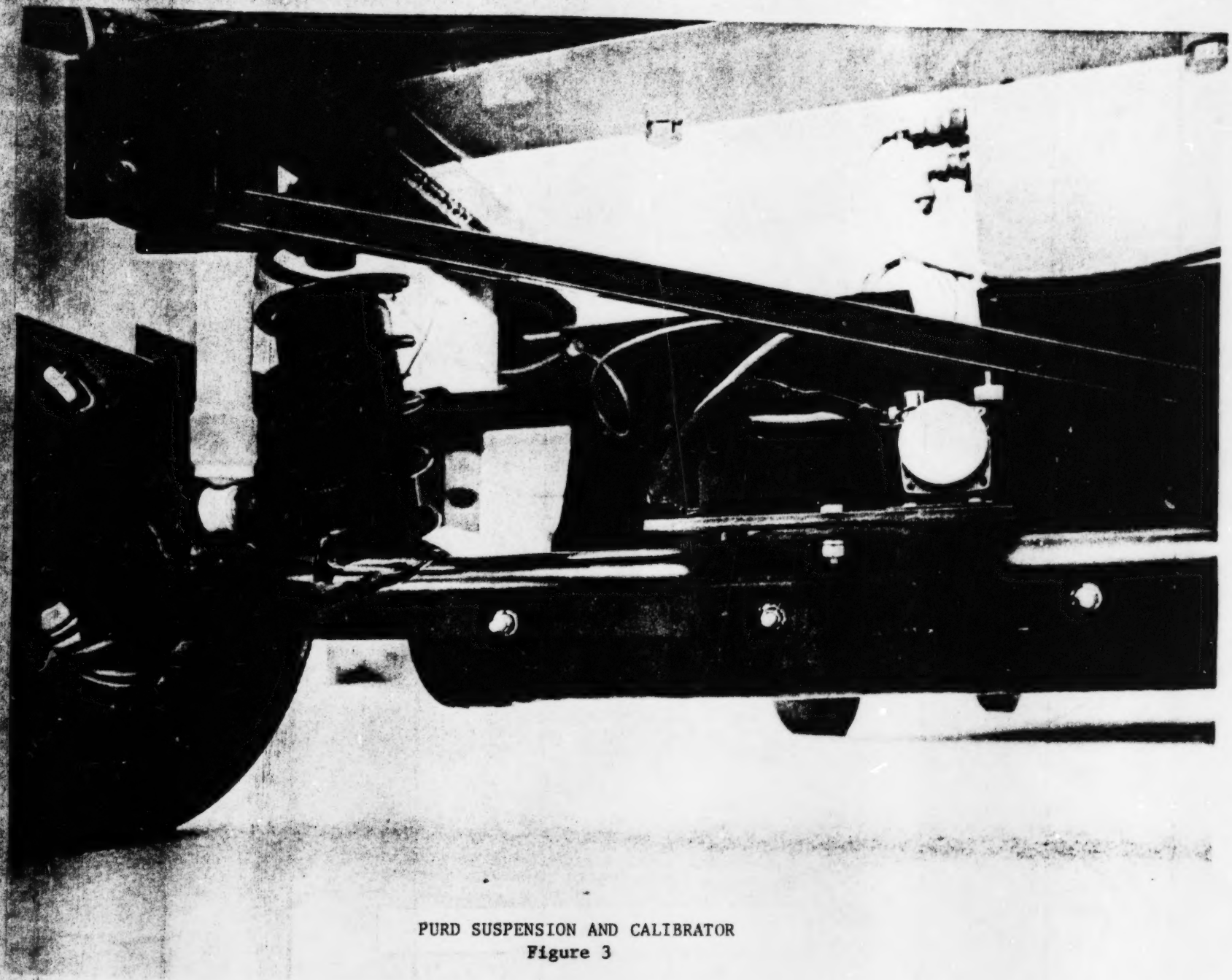
The accelerometer selected was an Endevco 2215E piezo-electric type. This accelerometer features high output level and excellent cross-axle rejection. The output from the accelerometer is buffered by a unity gain amplifier in the trailer and connected by a cable to the front seat controller in the vehicle. The analog board in the controller integrates the signal and then computes the RMS value. The



BASIC PURD TRAILER
Figure 1



PURD LOAD BOX AND ELECTRONICS
Figure 2

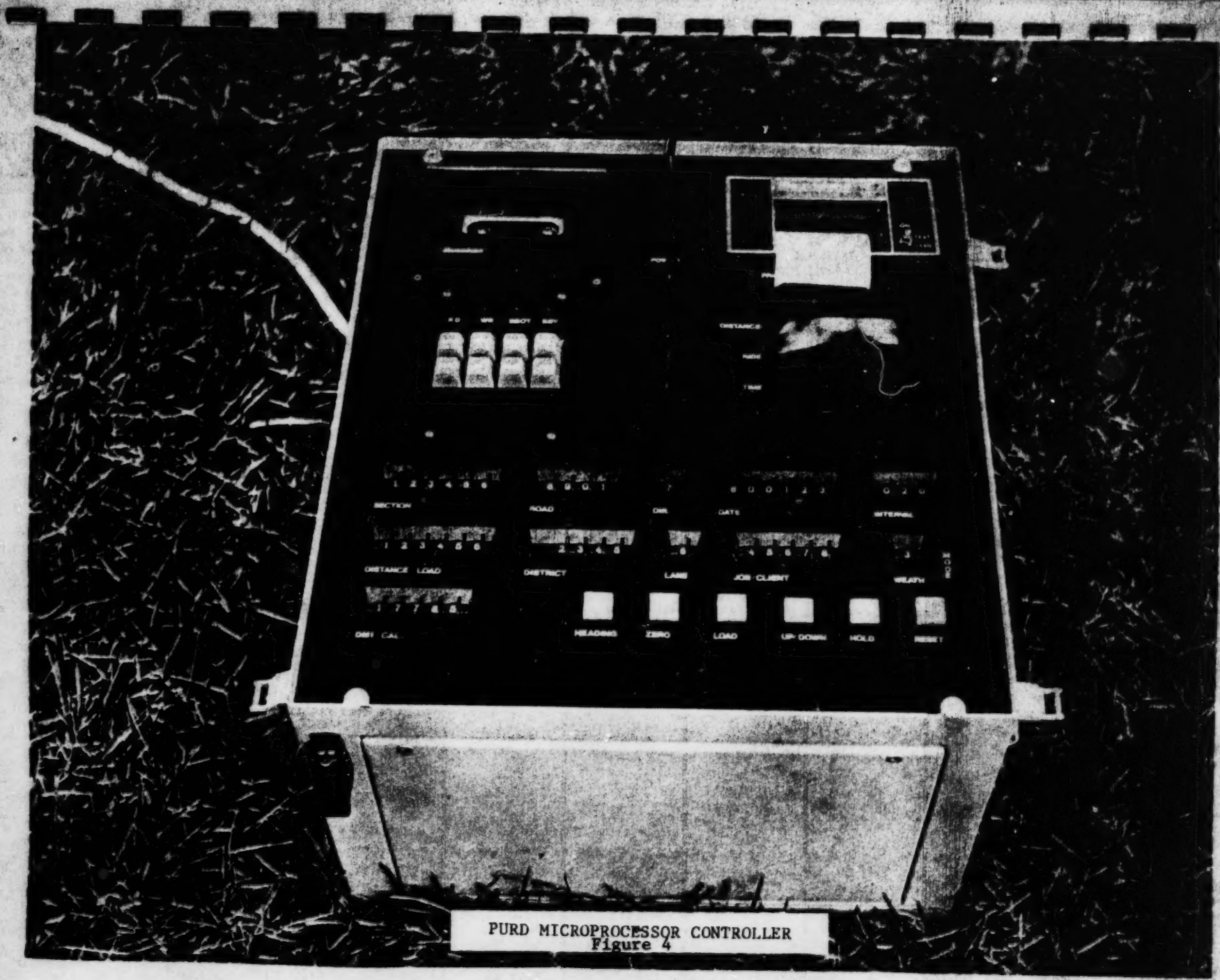


PURD SUSPENSION AND CALIBRATOR
Figure 3

RMS value is converted to a frequency which is counted over a time interval which is dependent upon the vehicle speed. An implicit integration results from the accumulation of the RMS value over a time interval determined by the sample interval in metres and the vehicle speed. The resulting number in the counter is then a "millimetres per kilometre statistic" showing the total vertical axle displacement for a unit horizontal distance.

Power for the electronic equipment is derived from the vehicle alternator. If the electrical system is heavily loaded an additional alternator is usually installed. The 12 volt DC power from the alternator is converted to 117 VAC by a 200 WATT sinewave inverter.

The control panel and some optional accessories since developed are shown in Figure 4.



PURD MICROPROCESSOR CONTROLLER
Figure 4

3. PHASE I TEST

3.1 Purpose of the Test

The first phase of testing was carried out in the hinterland of Paris, Ontario, on various surface types. The main purpose of the test was to collect data for analysis for repeatability and correlation with other existing equipment. The effects of different tow vehicles on repeatability was investigated in this test using two different types of trucks.

3.2 Data Collection

Data was collected by Highway Products International Inc. and its parent Federal Technical Surveys Inc. Highway Products provided the trailer and electronics while Federal Technical Surveys provided the tow vehicles and personnel. The data collection was supervised and interpretation of results carried out by Pavement Management Systems (PMS) Ltd. an independent firm of pavement management consulting engineers.

Since it was proposed to add an attachment in future to measure the depth of ruts in the wheel track paths behind the trailer, the mechanical portion of the rut bar was attached to the trailer and included in the tests.

3.3 Results

1. The results show that the device has excellent repeatability of roughness measurement.

2. There does not appear to be a significant tow vehicle effect.

3. Useful Riding Comfort Index equations were developed using the data collected together with a panel rating of the surface by selected individuals.

A completed copy of the test results and the conclusions of PMS is included in Appendix A.

4. PHASE II TEST

4.1 Purpose of the Test

The purpose of the test was to demonstrate usage of the device by a Canadian highway authority. The Province of Newfoundland was selected for this test since PMS Ltd. has done previous studies and reports on the pavement condition of some of the Trans Canada Highway sections in the province.

4.2 Data Collection

Data was collected over 860 kilometres on 55 sections of road. Sampling was done at 50 metre intervals at a speed of 50 km per hour.

4.3 Results

The results were correlated with a previous survey carried out in 1979 using a machine known as the ARAN (Automatic Road Analyzer) which also collects response type roughness data. ARAN has been widely accepted as a dependable source of roughness data. A correlation equation, a regression curve and some samples of the actual data collected are included in Appendix B.

Roughness data collected by the PURD in Newfoundland was used to calculate the RCI (Riding Comfort Index) used in a report prepared for: Department of Transportation and Communications, Government of Newfoundland and Labrador entitled, "The Present Pavement Condition of the Trans Canada Highway Sections in Newfoundland". This report was prepared by Pavement Management Systems Ltd. under contract from the province. The materials contained in Appendix B are excerpts from this three volume report.

For the purposes of the Newfoundland report, Pavement Management Systems Ltd. referred to the PURD as a new version of the ARAN unit. This explains why the headings in the tables and figures refer to the "ARAN" unit rather than PURD.

APPENDIX A

TECHNICAL MEMORANDUM ON PURD EVALUATION

TECHNICAL MEMORANDUM

FROM: W.K. Smeaton, Staff Engineer

TO: Don Kobi, President, FTS Inc.

RE: PURD EVALUATION

GENERAL INTRODUCTION

This technical memorandum contains the results of statistical analyses conducted for FTS Inc. by PMS Ltd. The PURD unit was employed to measure roughness on a local circuit of pavements using two different tow vehicles at different speeds and sample intervals. The evaluations and comparisons conducted, as outlined in a memo dated November 5, 1982, consisted of the following:

1. Tow Vehicle A with weights and rut bar
   a) Repeatability Study
   b) Speed Study
   c) Local Circuit Rural RCI Correlation Study

2. Comparison of Tow Vehicle A (with rut bar and weights) with Tow Vehicle B (with rut bar and weights)

Table 1 summarizes the number of samples obtained for each of the

TABLE 1

SUMMARY OF NUMBER OF SAMPLES OBTAINED FOR EACH RUN

TOW VEHICLE / SAMPLE INTERVAL, M / SPEED, MPH / REPLICATE		A						B	
		20			50			20	50
		20		25	20	30		20	30
		1	2	1	1	1	2	1	1
SECTION	1	104	-	104	41	41*	-	-	41
	2	59	-	59	23	23*	-	-	23
	3	129	-	129	51	51*	-	-	51
	4	154	-	154	61	61*	-	-	61
	51	84	-	84	33	33	-	-	33
	52	67	-	67	26	26*	-	-	26
	53	42	-	42	16	16*	-	-	16
	6	152	-	152	60	60*	-	-	60
	7	69	-	69	27	27*	-	-	27
	9	147	-	147	58	58*	-	-	58
	10	24	-	24	9	9	-	-	9
	11	119	-	119	47	47	-	-	47
	12	287	-	287	114	114	-	-	114
	13	24	24	24	9	9	9	24	-
	14	59	59	59	23	23	23	59	-
	15	44	44	44	17	17	17	44	-
	16	49	49	49	19	19	19	49	-
	17	31	31	31	12	12	12	31	-
	18	56	56	56	22	22	22	56	-
	19	57	57	57	22	22**	22**	57	-
	20	82	82	82	32	32**	32**	82	-
	21	62	62	62	24	24**	24**	62	-
	22	72	72	72	28	28	28	72	-

(*) Rut depth and condition also measured

(**) Rut depth also measured

runs made. The runs where condition and/or rut depth were also measured during the roughness survey are noted on this table.

Attachment A contains a technical description of the statistical procedure applied to Tasks 1a) and 2. above.

REPEATABILITY STUDY OF PURD WITH RUT BAR AND WEIGHTS USING TOW VEHICLE A

Table 2 shows a summary of the data used in the repeatability analysis. The highlights of the non-paired comparison (see Attachment A) are presented in Table 3. The test results for each comparison are shown as an equal or unequal sign in a circle. The equal sign means that there is no statistical difference at the 95% level of confidence, whereas the unequal sign means that the values being compared are significantly different.

These results tend to indicate that there appears to be excellent repeatability.

SPEED STUDY OF PURD WITH RUT BAR AND WEIGHTS USING TOW VEHICLE A

Table 4 shows a summary of the data used in the speed study. Only 4 combinations of speed and sample interval were tested, therefore, only two speed relations were developed: A. conversion of roughness at 25 mph and 20 metre intervals (R_{2520}) to roughness at 20 mph and 20 metre intervals (R_{2020}) and B. conversion of roughness at

TABLE 2

SUMMARY OF DATA FOR REPEATABILITY ANALYSIS OF THE PURD WITH RUT BAR AND WEIGHT USING TOW VEHICLE A

SECTION NUMBER	SPEED (MPH)	SAMPLE INTERVAL (metres)	RUN NO.	MEAN ROUGHNESS	STANDARD DEVIATION OF ROUGHNESS	MEAN ELAPSED TIME	STANDARD DEVIATION OF ELAPSED TIME	NO. OF SAMPLES	TIRE PRESSURE (PSI)	SUSPENSION PRES- (PSI)	ELECTRONICS TEMP. (°F)	AMBIENT AIR TEMP. (°F)	
13	20	20	1	10.96	1.01	2.36	0.07	24	28	15	66	66	
			2	11.13	1.35	2.30	0.05	24	28	15	66	66	
	30	50	1	33.05	3.64	3.85	0.12	9	30	15.5	81	75	
			2	31.49	2.63	3.83	0.08	9	31.5	15.5	88	78	
14	20	20	1	10.34	3.78	2.29	0.06	59	28	15	66	66	
			2	10.76	4.12	2.26	0.07	59	28	15	66	66	
	30	50	1	31.15	9.37	3.89	0.06	23	30	15.5	81	75	
			2	33.11	9.09	3.78	0.10	23	31.5	15.5	88	78	
15	20	20	1	8.1265	4.4633	2.36	0.2962	43	28	15	66	66	had to reject 15th reading
			2	7.8565	4.2670	2.33	0.1097	43	28	15	66	66	
	30	50	1	22.78	6.88	3.80	0.07	17	30	15.5	81	75	
			2	22.82	7.77	3.73	0.07	17	31.5	15.5	88	78	
16	20	20	1	3.84	0.30	2.44	0.10	49	28	15	66	66	
			2	3.85	0.58	2.33	0.13	49	28	15	68	68	
	30	50	1	11.17	1.25	3.89	0.09	19	30	15.5	81	75	
			2	11.42	0.99	3.73	0.09	19	31.5	15.5	88	78	
17	20	20	1	8.53	2.84	2.30	0.06	31	28	15	66	66	
			2	7.90	2.65	2.23	0.06	31	28	15	68	68	
	30	50	1	24.88	5.27	3.76	0.08	12	30	15.5	81	75	
			2	23.54	6.27	3.71	0.07	12	31.5	15.5	88	78	

TABLE 2

(continued)

SECTION #	SPEED (MPH)	INTERVAL in metres	RUN #	MEAN ROUGH-NESS	STAND. DEV. OF ROUGH-NESS	MEAN ELAP-SED TIME	STAND DEV. OF ROUGH-NESS	# OF SAM-PLES	TIRE PRES-SURE	SUSPENSIONS PRESSURE	ELEC. TEMP.	AMBIENT AIR TEMP. (°F)
18	20	20	1	8.91	6.17	2.37	0.11	56	28	15	66	66
			2	8.72	5.86	2.24	0.10	56	28	15	68	68
	30	50	1	25.87	11.69	3.86	0.12	22	30	15.5	81	75
			2	26.01	12.08	3.79	0.07	22	31.5	15.5	88	78
19	20	20	1	15.38	3.84	2.22	0.06	57	27.5	14	66	60
			2	15.17	3.72	2.19	0.06	57	28.5	14	74	67
	30	50	1	45.40	6.59	3.83	0.07	22	29.5	25	81	73
			2	44.24	6.19	3.84	0.06	22	29.5	15	81	73
20	20	20	1	15.69	4.33	2.20	0.08	82	27.5	14	66	60
			2	15.47	4.39	2.20	0.05	82	28.5	14	74	67
	30	50	1	44.33	10.33	3.83	0.06	32	29.5	15	81	73
			2	44.26	11.25	3.83	0.07	32	29.5	15	81	73
21	20	20	1	19.01	5.95	2.23	0.12	62	27.5	14	66	60
			2	18.89	6.16	2.27	0.10	62	28.5	14	74	67
	30	50	1	54.76	11.80	3.84	0.07	24	29.5	15	81	73
			2	54.02	12.05	3.85	0.07	24	29.5	15	81	73
22	20	20	1	4.40	0.58	2.23	0.07	72	30.5	15	89	80
			2	4.31	0.59	2.24	0.07	72	30.5	15	89	80
	30	50	1	12.90	1.17	3.84	0.05	28	30.5	15	89	80
			2	12.94	1.17	3.84	0.04	28	30.5	15	89	80

TABLE 3

REPEATABILITY ANALYSIS FOR PURD WITH RUT BAR AND WEIGHTS USING TOW VEHICLE A

SECTION	SPEED/INT.	COMPARISON	n	F_{calc}	F_{TAB}	RESULT OF F-TEST	Equal Variances		Unequal Variance	t_{tab}	RESULT OF F-TEST
							S^2	t_{calc}	t'		
13	20/20	1 vs 2	24	1.34	F(24,23)=2.01	=	1.4213	0.699	-	t_{∞} =1.96	=
13	30/50	1 vs 2	9	1.38	F(8, 8)=3.44	=	10.083	1.474	-	t_{∞} =1.96	=
14	20/20	1 vs 2	59	1.09	F(60,60)=1.53	=	15.6314	1.585	-	t_{∞} =1.96	=
14	30/50	1 vs 2	23	1.03	F(24,22)=2.03	=	85.2125	1.018	-	t_{∞} =1.96	=
15	20/20	1 vs 2	43	1.02	F(60,60)=1.53	=	18.623	0.410	-	t_{∞} =1.96	=
15	30/50	1 vs 2	17	1.13	F(20,16)=2.28	=	53.85	0.022	-	t_{∞} =1.96	=
16	20/20	1 vs 2	49	1.93	F(40,40)=1.69	≠			0.1072	t_{∞} =1.96	=
16	30/50	1 vs 2	19	1.26	F(20,18)=2.19	=	1.2713	0.966	-	t_{∞} =1.96	=
17	20/20	1 vs 2	31	1.07	F(30,30)=1.84	=	7.544	1.277	-	t_{∞} =1.96	=
17	30/50	1 vs 2	12	1.19	F(12,11)=2.79	=	33.543	0.801	-	t_{∞} =1.96	=
18	20/20	1 vs 2	56	1.05	F(60,60)=1.53	=	36.204	0.236	-	t_{∞} =1.96	=
18	30/50	1 vs 2	22	1.03	F(24,21)=2.05	=	141.291	0.055	-	t_{∞} =1.96	=
19	20/20	1 vs 2	57	1.03	F(60,60)=1.53	=	14.292	0.419	-	t_{∞} =1.96	=
19	30/50	1 vs 2	22	1.06	F(24,22)=2.03	=	40.8721	0.851	-	t_{∞} =1.96	=
20	20/20	1 vs 2	82	1.01	F(120,120)=1.35	=	19.0105	0.457	-	t_{∞} =1.96	=
20	30/50	1 vs 2	32	1.09	F(40,40)=2.11	=	116.636	0.037	-	t_{∞} =1.96	=
21	20/20	1 vs 2	62	1.04	F(120,120)=1.35	=	36.67	0.156	-	t_{∞} =1.96	=
21	30/50	1 vs 2	24	1.02	F(24,23)=2.70	=	142.22	0.304	-	t_{∞} =1.96	=
22	20/20	1 vs 2	72	1.02	F(120,120)=1.35	=	0.3423	1.305	-	t_{∞} =1.96	=
22	30/50	1 vs 2	28	1.00	F(30,27)=2.47	=	1.3689	0.181	-	t_{∞} =1.96	=

TABLE 4

SUMMARY OF SPEED STUDY DATA FOR PURD WITH RUT BAR & WEIGHT USING TOW VEHICLE A

	20 m Sample Interval		50 m Sample Interval	
SECTION NUMBER	20 mph	25 mph	20 mph	30 mph
1	9.10	8.66	23.05	27.79
2	10.34	10.50	25.33	28.70
3	9.31	10.75	23.45	29.82
4	6.85	7.25	17.26	20.25
51	7.65	8.30	19.11	21.35
52	7.48	7.82	18.35	21.44
53	6.63	7.29	15.87	19.27
6	16.55	17.25	40.79	47.73
7	4.32	4.51	10.62	13.14
9	6.50	6.98	16.26	18.46
10	10.93	12.97	24.85	35.45
11	9.63	10.79	24.67	28.83
12	9.22	9.94	23.08	27.17
13	11.05	11.44	28.07	32.27
14	10.55	11.40	26.68	32.13
15	7.99	8.25	20.14	22.80
16	3.85	3.83	9.83	11.30
17	8.22	7.95	19.15	24.21
18	8.82	9.49	21.97	25.94
19	15.28	16.74	37.16	44.82
20	15.58	16.00	38.47	44.30
21	18.95	20.27	47.16	54.39
22	4.36	4.48	11.37	12.92

20 mph and 50 metre intervals (R_{2050}) to roughness at 30 mph and 50 metre intervals (R_{3050}). Linear regression analysis was employed to develop these equations which are described below.

I. Correlation of R_{2520} to R_{2020}:

$$R_{2020} = 0.2189651 + 0.91941 * R_{2520} \text{ , } n = 23$$

$$R^2 = 0.985139 \qquad SE = 0.4885515$$

II. Correlation of R_{2050} to R_{3050}:

$$R_{3050} = 0.52567 + 1.1652685 * R_{2050} \text{ , } n = 23$$

$$R^2 = 0.9806772 \qquad SE = 1.6101504$$

III. Correlation of R_{2020} to R_{3050}

$$R_{3050} = 0.6242328 + 2.8755198 * R_{2020} \text{ , } n = 23$$

$$R^2 = 0.9897876 \qquad SE = 1.1705675$$

RURAL RCI CORRELATION STUDY OF PURD WITH RUT BAR AND WEIGHTS USING TOW VEHICLE A

The RCI panel ratings conducted in July 1982 by PMS Ltd. for correlation with the SIE ARAN unit on the local test circuit were employed to develop a rural RCI correlation. The RCI on section 6 was rejected due to the performance of significant maintenance between the panel ratings and PURD testing which resulted in a much rougher surface.

For the rural relationship, roughness measured at 30 mph and 50 metre intervals (R_{3050}) was correlated to the average RCI from the ratings of 4 panel members using the data for 19 sections on the circuit shown below.

SECTION	R_{3050}	RCI
1	27.79	5.32
2	28.70	4.82
3	29.82	3.56
4	20.25	5.14
7	13.14	7.49
9	18.46	5.80
10	35.45	3.07
11	28.83	4.17
12	27.17	4.55
13	32.27	5.04
14	32.13	3.66
15	22.80	6.41
16	11.30	8.04
17	24.21	5.55
18	25.94	4.72
19	44.82	2.80
20	44.30	2.60
21	54.39	2.80
22	12.92	6.78

The regression analysis resulted in the following relation:

$RCI = 16.311007 - 3.5155174 \ln (R_{3050})$ or

$RCI = 16.311007 - 8.094778 \log (R_{3050})$

$R^2 = 0.8754209$, SE = 0.576309 ; for $\hat{RCI} = 0$, $R_{3050} = 103.52$;
for $\hat{RCI} = 10$, $R_{3050} = 6.02$;
for $\hat{RCI} = 5$, $R_{3050} = 24.96$

COMPARISON OF TOW VEHICLE A AND B FOR PURD WITH RUT BAR AND WEIGHTS

As with the repeatability study, the data used in this comparison is presented in tabular form in Table 5. The comparison was conducted for R_{3050} on sections 1 to 12 and for R_{2020} on sections 13 to 22, using the non-paired comparison test procedure outlined in Attachment A.

Table 6 presents the results of these comparisons made in the same format as Table 3. In general there does not seem to be a significant tow vehicle effect.

SUMMARY OF PRINCIPAL FINDINGS

For the combinations of speed and sample interval studies for the PURD with rut bar and weights, the results of these analyses can be summarized as follows:

1.a REPEATABILITY (TOW VEHICLE A): There appears to be excellent repeatability of roughness measurement

TABLE 5

SUMMARY OF DATA FOR COMPARISON OF TOW VEHICLES A & B FOR PURD WITH RUT BAR AND WEIGHTS

SEC #	SPEED MPH	INTERUM in metres	TOW VEHICLE	MEAN ROUGHNESS	STAND DEV. OF ROUGHNESS	ELAP-SED TIME	STAND DEV. OF ROUGHNESS	# OF SAMPLES	TIRE PRESSURE	SUSPEN-SION PRESSURE	ELEC. TEMP.	AMBIENT AIR TEMP (°F)
1	30	50	A	27.79	3.32	4.00	0.14	41	28.5	14	76	72
			B	26.84	3.49	3.79	0.14	41	28	15	64	64
2	30	50	A	28.70	4.95	4.03	0.06	23	28.5	14	76	72
			B	28.20	5.14	3.84	0.06	23	28	15	64	64
3	30	50	A	29.82	8.81	3.99	0.07	51	28.5	14	76	72
			B	30.46	8.58	3.78	0.10	51	28	15	64	64
4	30	50	A	20.25	2.40	3.93	0.13	61	28.5	14	76	72
			B	20.06	2.48	3.74	0.07	61	28	14.5	61	61
51	30	50	A	21.35	2.50	3.99	0.05	33	29	14	82	76
			B	21.64	3.22	3.73	0.05	33	28	14.5	61	61
52	30	50	A	21.44	2.60	3.96	0.18	26	29	14	82	76
			B	20.93	2.45	3.74	0.05	26	28	14.5	61	61
53	30	50	A	19.27	3.51	4.00	0.05	16	29	14	82	76
			B	19.04	3.73	3.74	0.09	16	28	14.5	61	61
6	30	50	A	47.73	12.49	3.98	0.13	60	29	14	82	76
			B	42.42	11.71	3.79	0.08	60	28	14.5	61	61
7	30	50	A	13.14	1.27	3.97	0.07	27	30	15	88	79
			B	13.50	1.23	3.71	0.09	27	28	14.5	61	61
9	30	50	A	18.46	2.48	4.01	0.10	58	30	15	88	79
			B	18.73	2.42	3.79	0.06	58	29	14.5	67	65
10	30	50	A	35.45	9.42	3.99	0.08	9	30	15	88	79
			B	36.38	8.72	3.80	0.08	9	29	14.5	67	

TABLE 5

(continued)

SEC #	SPEED MPH	INTERUM in m.	TOW VEHICLE	MEAN ROUGHNESS	STAND DEV. OF ROUGHNESS	MEAN ELAPSED TIME	STAND DEV. OF ROUGHNESS	# OF SAMPLES	TIRE PRESSURE	SUSPEN-SION PRESSURE	ELEC. TEMP.	AMBIENT AIR TEMP (°F)	
11	30	50	A	28.83	5.19	4.04	0.05	47	31	15	94	83	
			B	28.40	5.24	3.78	0.09	47	29	14.5	67	65	
12	30	50	A	27.17	4.80	3.97	0.15	114	31	15	94	83	
			B	27.07	4.23	3.78	0.08	114	29	14.5	67	65	
13	20	20	A	11.045	1.170	2.33	0.067	24	28	15	66	66	
			B	11.25	1.50	2.24	0.06	24	29	14.5	67	65	
14	20	20	A	10.55	3.926	2.275	0.066	59	28	15	66	66	
			B	10.27	3.36	2.24	0.08	59	31	15	74	70	
15	20	20	A	7.99	4.2671	2.345	0.2212	43	28	15	66	66	had to reject 15th reading
			B	8.13	4.3495	2.25	0.1112	43	31	15	74	70	
16	20	20	A	3.845	0.406	2.385	0.127	49	28	15	66 68	66 68	
			B	4.53	0.60	2.30	0.05	49	31	15	74	70	
17	20	20	A	8.215	2.72	2.265	0.069	31	28	15	66 68	66 68	
			B	8.76	2.81	2.24	0.06	31	31	15	74	70	
18	20	20	A	8.815	5.964	2.305	0.123	56	28	15	66 68	66 68	
			B	9.29	5.19	2.26	0.06	56	31	15	74	70	
19	20	20	A	15.275	3.7486	2.205	0.06	57	27.5 28.5	14	66 74	60 67	
			B	15.53	3.64	2.21	0.06	57	32	15	80	74	
20	20	20	A	15.58	4.3348	2.20	0.066	82	27.5 28.5	14	66 74	60 67	
			B	15.93	4.03	2.22	0.07	82	32	15	80	74	
21	20	20	A	18.95	6.0072	2.25	0.1114	62	27.5 28.5	14	66 74	60 67	
			B	19.41	5.50	2.21	0.06	62	32	15	80	74	
22	20	20	A	4.355	0.583	2.235	0.06969	72	30.5	15	89	80	
			B	5.96	0.61	2.24	0.05	72	32	15	80	74	

TABLE 6

COMPARISON OF TOW VEHICLES A & B FOR PURD WITH RUT BAR AND WEIGHTS

SECTION	SPEED/INT.	COMPARISON	n	F_{calc}	F_{TAB}	RESULT OF F-TEST	Equal Variances		Unequal Variances	t_{tab}	RESULT OF t-TEST
							S^2	t_{calc}	t'		
1	30/50	A vs B	41	1.05	F(120,120)=1.35	=	11.60	1.786		t_∞ =1.96	=
2	30/50	A vs B	23	1.04	F(120,120)=1.35	=	25.461	0.475		t_∞ =1.96	=
3	30/50	A vs B	51	1.03	F(120,120)=1.35	=	75.616	0.526		t_∞ =1.96	=
4	30/50	A vs B	61	1.03	F(120,120)=1.35	=	5.955	0.608		t_∞ =1.96	=
51	30/50	A vs B	33	1.29	F(120,120)=1.35	=	8.3092	0.578		t_∞ =1.96	=
52	30/50	A vs B	26	1.06	F(120,120)=1.35	=	6.3813	1.029		t_∞ =1.96	=
53	30/50	A vs B	16	1.06	F(120,120)=1.35	=	13.1165	0.254		t_∞ =1.96	=
6	30/50	A vs B	60	1.07	F(120,120)=1.35	=	146.562	3.397		t_3 =3.182	≠
7	30/50	A vs B	27	1.03	F(120,120)=1.35	=	1.5629	1.496		t_∞ =1.96	=
9	30/50	A vs B	58	1.02	F(120,120)=1.35	=	6.0034	0.839		t_∞ =1.96	=
10	30/50	A vs B	9	1.08	F(120,120)=1.35	=	82.3874	0.307		t_∞ =1.96	=
11	30/50	A vs B	47	1.01	F(120,120)=1.35	=	27.197	0.565		t_∞ =1.96	=
12	30/50	A vs B	14	1.13	F(120,120)=1.35	=	20.466	0.236		t_∞ =1.96	=
13	20/20	A vs B	24	1.282	F(120,120)=1.35	=	1.809	0.747		t_∞ =1.96	=
14	20/20	A vs B	59	1.168	F(120,120)=1.35	=	13.352	0.589		t_∞ =1.96	=
15	20/20	A vs B	43	1.02	F(120,120)=1.35	=	27.667	0.1745		t_∞ =1.96	=
16	20/20	A vs B	49	1.48	F(60,60) =1.53	=	0.2624	9.360		t_∞ =4.303	≠
17	20/20	A vs B	31	1.03	F(120,120)=1.35	=	7.647	1.097		t_∞ =1.96	=
18	20/20	A vs B	56	1.149	F(120,120)=1.35	=	31.253	0.636		t_∞ =1.96	=
19	20/20	A vs B	57	1.03	F(120,120)=1.35	=	13.651	0.521		t_∞ =1.96	=
20	20/20	A vs B	82	1.076	F(120,120)=1.35	=	17.516	0.757		t_∞ =1.96	=
21	20/20	A vs B	62	1.092	F(120,120)=1.35	=	33.168	0.629		t_∞ =1.96	=
22	20/20	A vs B	2	1.046	F(120,120)=1.35	=	0.356	22.83		t_1 =12.706	≠

1.b SPEED STUDY (TOW VEHICLE A):

$R_{2020} = 0.2189651 + 0.91941 * R_{2520}$; $R^2 = 0.985$; SE = 0.49

$R_{3050} = 0.52567 + 1.1652685 * R_{2050}$; $R^2 = 0.981$; SE = 1.61

$R_{3050} = 0.6242328 + 2.8755198 * R_{2020}$; $R^2 = 0.989$; SE = 1.17

1.c RURAL RCI CORRELATION (TOW VEHICLE A):

$RCI = 16.311007 - 3.5155174 \ln (R_{3050})$ or

$RCI = 16.311007 - 8.094778 \log_{10} (R_{3050})$

$R^2 = 0.875$; SE = 0.576

2. COMPARISON OF TOW VEHICLES: Generally there does not appear to be a significant tow vehicle effect.

APPENDIX B

RELATIONSHIP BETWEEN RCI AND MEASURED ROUGHNESS

RELATIONSHIP BETWEEN RCI AND MEASURED ROUGHNESS

The relationship between RCI and measured ARAN roughness used in this program was developed in Novemeber 1979 for Newfoundland conditions.

The relationship shown in Figure D was presented in a previous report entitled: "Flexible Pavement Serviceablility (RCI) - Roughness Correlation Project for the Government of Newfoundland and Labrador".

Since 1979, the specific ARAN unit employed in that project had been extensively used and has been replaced by a new version with enhanced capabilities and up to date technology. A correlation program was conducted and analyzed by PMS to assist in the transferability and compatibility of various units and data. The RCI-roughness equation for the ARAN unit employed in Newfoundland in 1982, is: $RCI=20.4603 - 5.7530 \log_e R$ where RCI is the Newfoundland opinion as to ride quality from 1979 correlation study and R is calibrated and speed corrected roughness value for the unit used in 1982.

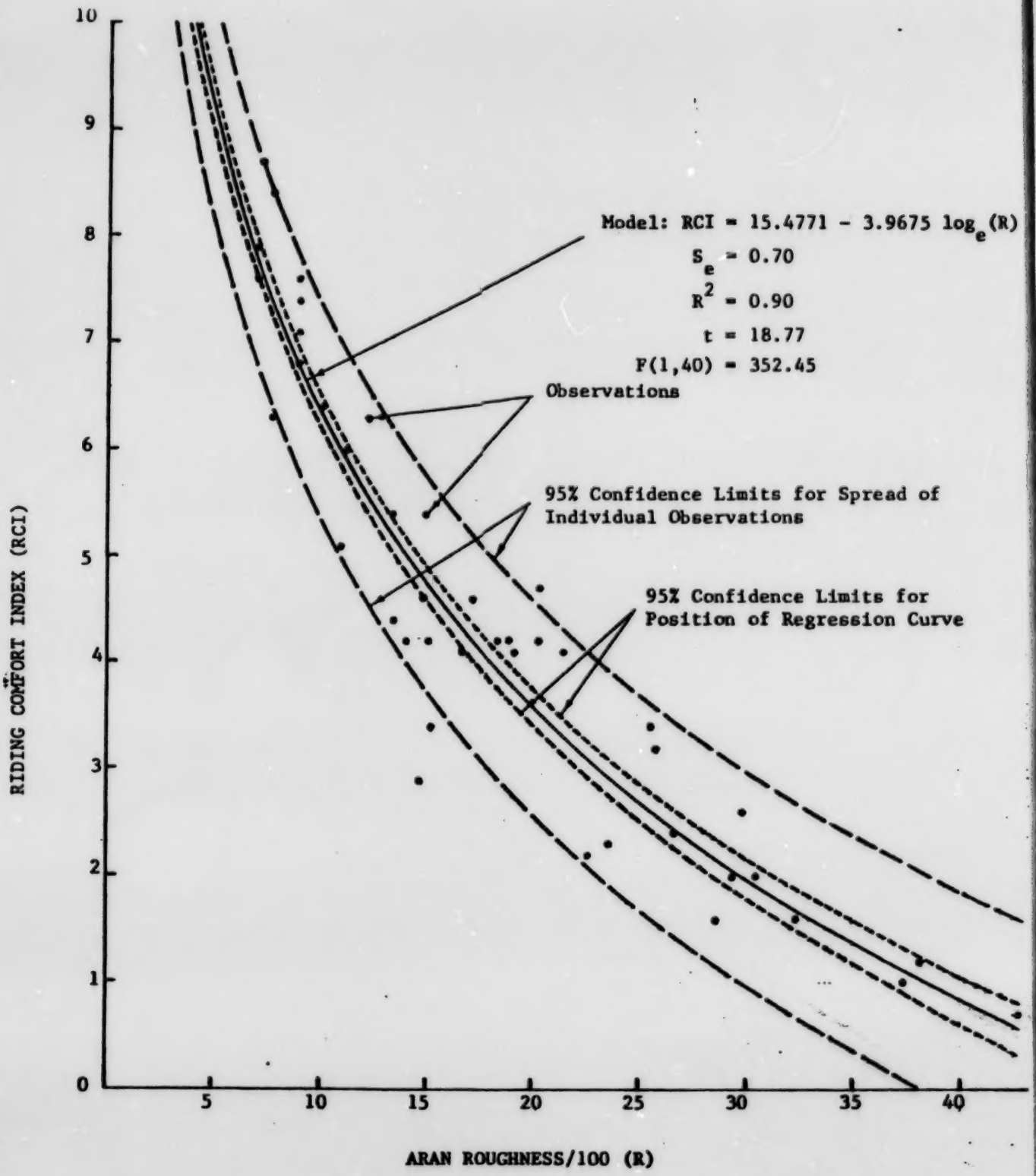


FIGURE D - ROUGHNESS VERSUS RIDING COMFORT INDEX RELATIONSHIP FOR RURAL ROADS IN THE PROVINCE OF NEWFOUNDLAND

PAVEMENT MANAGEMENT SYSTEMS LIMITED

CLIENT : NEWFOUNDLAND & LABRADOR D O T & C
PROJECT : ARAN ANALYSIS SURVEY
DATE : SUMMER 1982

SECTION : 0012
LANE : WEST BOUND LANE # 1
LOCATION : JCT DEEP BIGHT RT TO SHOAL HARB RIVER BRIDGE

STATION	SPEED	ARAN ROUGHNESS ACTUAL	CALIB	RCI	REMARKS
00+100	51.42	14.77	14.77	5.0	OLD AC
00+150	48.64	12.72	12.72	5.8	OLD AC
00+200	47.36	13.39	13.55	5.5	OLD AC
00+250	47.36	14.06	14.22	5.2	OLD AC
00+300	44.99	15.42	16.05	4.5	OLD AC
00+350	44.99	12.45	12.98	5.7	OLD AC
00+400	44.99	12.15	12.67	5.9	OLD AC
00+450	44.99	11.63	12.13	6.1	OLD AC
00+500	43.89	14.16	14.94	4.9	OLD AC
00+550	43.89	11.93	12.61	5.9	OLD AC
00+600	43.89	18.71	19.69	3.3	OLD AC
00+650	43.89	23.48	24.68	2.0	OLD AC
00+700	44.99	17.04	17.72	3.9	OLD AC
00+750	44.99	15.32	15.94	4.5	OLD AC
00+800	46.14	12.78	13.13	5.6	OLD AC
00+850	44.99	13.16	13.71	5.4	OLD AC
00+900	44.99	12.32	12.84	5.8	OLD AC
00+950	43.89	12.55	13.26	5.6	OLD AC
01+000	41.85	11.90	12.89	5.8	OLD AC
01+050	40.90	11.06	12.14	6.1	OLD AC
01+100	43.89	12.19	12.88	5.8	OLD AC
01+150	46.14	13.17	13.53	5.5	OLD AC
01+200	46.14	14.95	15.35	4.7	OLD AC
01+250	46.14	18.08	18.54	3.7	OLD AC
01+300	46.14	11.68	12.00	6.2	OLD AC
01+350	47.36	12.00	12.14	6.1	OLD AC
01+400	48.64	10.69	10.69	6.8	OLD AC
01+450	48.64	12.28	12.28	6.0	OLD AC
01+500	47.36	12.51	12.66	5.9	OLD AC
01+550	46.14	14.18	14.56	5.1	OLD AC
01+600	44.99	13.23	13.78	5.4	OLD AC
01+650	46.14	13.27	13.63	5.4	OLD AC
01+700	47.36	14.73	14.90	4.9	OLD AC
01+750	44.99	15.00	15.61	4.7	OLD AC
01+800	46.14	13.43	13.79	5.4	OLD AC
01+850	47.36	12.90	13.05	5.7	OLD AC
01+900	48.64	11.58	11.58	6.4	OLD AC
01+950	47.36	12.42	12.57	5.9	OLD AC
02+000	47.36	13.01	13.16	5.6	OLD AC
02+050	46.14	12.81	13.16	5.6	OLD AC
02+100	46.14	14.20	14.58	5.0	OLD AC
02+150	46.14	12.28	12.62	5.9	OLD AC
02+200	47.36	12.10	12.24	6.0	OLD AC
02+250	46.14	10.37	10.67	6.8	OLD AC
02+300	44.99	13.06	13.61	5.4	OLD AC

CONTINUED

CLIENT : NEWFOUNDLAND & LABRADOR D O T & C
PROJECT : ARAN ANALYSIS SURVEY
DATE : SUMMER 1982

SECTION : 0010
LANE : WEST BOUND LANE # 1
LOCATION : ARNOLDS COVE OVERPASS TO JCT OLD BURIN HIGHWAY NEAR WELKOMIN

STATION	SPEED	ARAN ROUGHNESS ACTUAL	CALIB	RCI	REMARKS
06+850	47.36	9.92	10.04	7.2	NEW AC
06+900	46.14	14.04	14.42	5.1	NEW AC
06+950	44.99	15.50	16.13	4.5	NEW AC
07+000	44.99	11.67	12.17	6.1	NEW AC
07+050	44.99	13.69	14.26	5.2	NEW AC
07+100	44.99	11.34	11.83	6.2	NEW AC
07+150	44.99	13.64	14.21	5.2	NEW AC
07+200	44.99	14.72	15.32	4.8	NEW AC
07+250	46.14	11.72	12.05	6.1	NEW AC
07+300	47.36	15.13	15.30	4.8	NEW AC
07+350	48.64	13.03	13.03	5.7	NEW AC
07+400	48.64	11.90	11.90	6.2	NEW AC
07+450	47.36	11.64	11.78	6.3	NEW AC
07+500	47.36	9.96	10.08	7.2	NEW AC
07+550	48.64	10.60	10.60	6.9	NEW AC
07+600	48.64	10.92	10.92	6.7	NEW AC
07+650	48.64	15.75	15.75	4.6	NEW AC
07+700	47.36	12.07	12.21	6.1	NEW AC
07+750	48.64	10.79	10.79	6.8	NEW AC
07+800	48.64	11.20	11.20	6.6	NEW AC
07+850	47.36	10.38	10.51	6.9	NEW AC
07+900	47.36	13.15	13.30	5.6	NEW AC
07+950	47.36	10.78	10.91	6.7	NEW AC
08+000	46.14	10.31	10.60	6.9	NEW AC
08+050	44.99	9.99	10.43	7.0	NEW AC
08+100	44.99	9.11	9.52	7.5	NEW AC
08+150	46.14	10.23	10.52	6.9	NEW AC
08+200	47.36	10.80	10.93	6.7	NEW AC
08+250	46.14	12.25	12.59	5.9	NEW AC
08+300	44.99	11.49	11.98	6.2	NEW AC
08+350	44.99	11.02	11.50	6.4	NEW AC
08+400	44.99	13.28	13.83	5.3	NEW AC
08+450	46.14	11.08	11.39	6.5	NEW AC
08+500	46.14	10.45	10.75	6.8	NEW AC
08+550	46.14	10.03	10.32	7.0	NEW AC
08+600	44.99	11.04	11.52	6.4	NEW AC
08+650	46.14	11.21	11.52	6.4	NEW AC
08+700	46.14	11.82	12.15	6.1	NEW AC
08+750	46.14	13.65	14.02	5.3	NEW AC
08+800	46.14	10.75	11.05	6.6	NEW AC
08+850	47.36	10.32	10.45	7.0	NEW AC
08+900	47.36	10.19	10.32	7.0	NEW AC
08+950	47.36	9.12	9.24	7.7	NEW AC
09+000	48.64	11.13	11.13	6.6	NEW AC
09+050	47.36	10.38	10.51	6.9	NEW AC

CONTINUED